OPTIONS FOR REDUCING GLOBAL GREENHOUSE GAS EMISSIONS— A MODEL PROJECT FOR EFFICIENCY IMPROVEMENT IN COAL FIRED POWER PLANTS

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ABSTRACT

The concentration of greenhouse gases, particularly carbon dioxide (CO_2), in the earth's atmosphere has increased significantly   current levels are 30% higher than before the Industrial Revolution (1860). Of the many options to reduce global CO_2 emissions, improving the efficiency of existing coal-fired power plants presents significant near-term, low-cost opportunities. The US Agency for International Development, with technical assistance from the US Department of Energy's National Energy Technology Laboratory, is conducting a multi-year cooperative project in India that aims to reduce greenhouse gas emissions from existing power generation facilities. This very successful project can serve as a model for similar cooperative activities in other coal-dependent developing countries.

1) CLIMATE CHANGE

The concentration of greenhouse gases, particularly carbon dioxide (CO_2), in the earth's atmosphere has increased significantly. As shown in Figure 1, at 365 parts per million (ppm), the concentration of CO_2 in the atmosphere is up by about 15% from the 315-ppm level of the late 1950s, 30% higher than the 280-ppm level before the Industrial Revolution (1860), and the highest in the last 420,000 years.

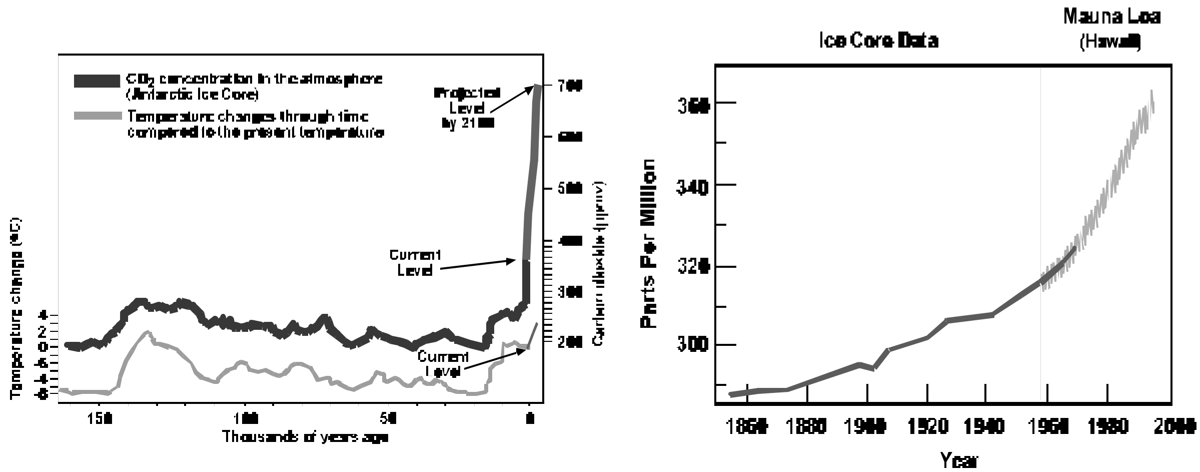

Figure 1. CO_2 Concentrations in the Atmosphere

In 1995, the Intergovernmental Panel on Climate Change (IPCC) issued its Second Assessment Report. The IPCC, which included 2,500 scientists and experts from 80 countries, reviewed the scientific knowledge base available at that time on climate change. Their three-volume report concluded that about 1 Fahrenheit increase in global average temperature over the past century was "…unlikely to be entirely natural in origin." The IPCC acknowledged that solar activity, changing tilts in the earth's axis, and aerosols in the atmosphere all influence climate, but they said, "…the balance of evidence suggests a discernable human influence on global climate."

As shown in Figure 2, a number of options exist to reduce global CO_2 emissions, with three of these being technical options. The two non-technical options—reducing population and reducing GDP—are not viewed by most as attractive or viable options. Figure 3 illustrates the first technical option, which is reducing the carbon intensity of fuel utilization or decarbonization. The transition to less carbon-intensive fuels—a trend that has been under way for the past 100 years—can be accelerated. Wood is the most carbon-intensive fuel. As technology has progressed, society moved to coal, then oil, and eventually natural gas. At the same time, energy use has dramatically increased. Today, the average H/C ratio for the fuels in use worldwide is about 2.0. This figure suggests that the world will evolve towards a methane-based economy in 2050, then transition to non-carbon-based energy sources, such as hydrogen, nuclear, or other, yet-to-be-developed sources. This trend is consistent with the current understanding that the worldwide fossil resource base is finite. While nuclear energy is an obvious choice, it is also a controversial choice. Long-term waste disposal and safety issues must be solved before nuclear power generation will again be an acceptable option in the United States and many other countries.

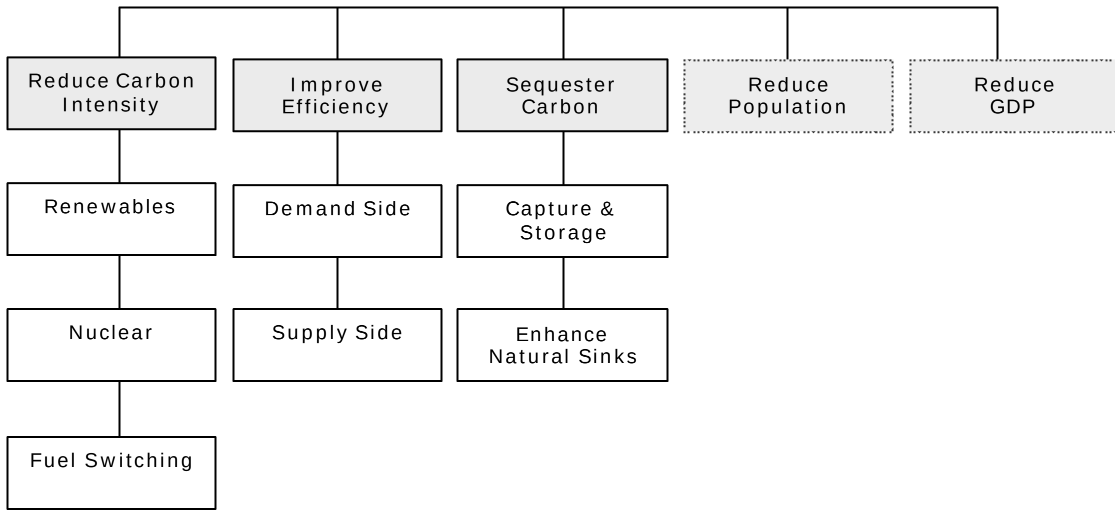

Figure 2. CO_2 Mitigation Options

The existing worldwide energy system works—it is relatively low cost, and represents a huge capital investment in an infrastructure. Ultimately, the world will likely need to transition to less carbon-intensive fuels, but a crash program to replace traditional fuels is neither realistic nor economically feasible. Natural gas may be the fuel that bridges the world to a less carbon-intensive future. The technologies and resources are available. Under a Business-as-Usual scenario, the Energy Information Administration (EIA) of the US Department of Energy (DOE) projects that gas use in the United States will increase by 50%— from 21 trillion cubic feet (tcf) in 1995 to 32 tcf in 2020. Gas prices in the United States are expected to remain constant until 2010 and then rise modestly. However, if gas consumption is doubled or tripled to reduce greenhouse gas (GHG) emissions, then two other issues must be considered: (1) How large is the world's natural gas reserve base? and (2) What price will consumers have to pay to have that gas produced, transmitted, and delivered? Worldwide, gas reserves are estimated to be 5,000 tcf, which is equal to a 65-year supply at current production rates— a very finite resource. The wildcard in gas reserve estimates may be methane hydrates— methane molecules encased in an ice latticework— which are found principally in arctic regions and under the ocean floor. If current estimates are accurate, hydrates could potentially provide a several-hundred-year supply of gas. However, the technology to produce this gas does not currently exist. If it is learned how to recover this gas, it will likely be difficult and expensive to produce. Research directed at location and production of gas hydrates is underway in the United States and other countries.

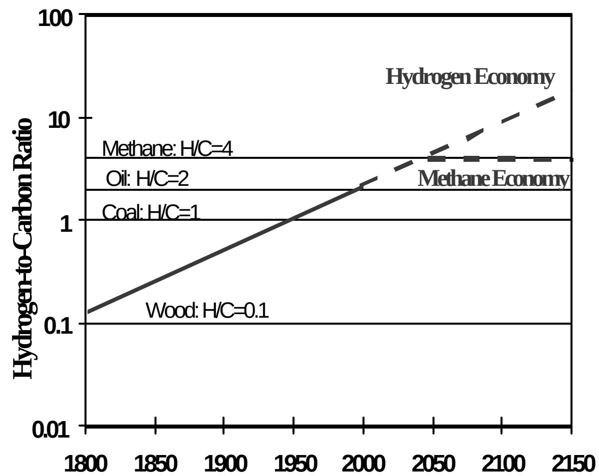

Figure 3. Trends in Fuel H/C Ratio for Global Energy

Renewable energy is an obvious option for reducing GHG emissions. The traditional renewables, hydro and biomass, already provide almost 20% of the world's total energy (although much of the biomass is used by primitive or non-commercial means in developing countries). Commercial developers are now showing tremendous interest in the emerging renewables: solar, wind, and geothermal. However, as with fossil energy, each of these energy sources has its own set of environmental and cost issues that need to be addressed before they will see widespread commercialization without a substantial increase in electric cost or government subsidies.

Internationally, most biomass is wood, a depleting resource. In the United States, most biomass consists of lumber industry residues or municipal solid waste. If dedicated forests and/or crops are used to produce biomass fuels, large amounts of land near a power plant will be needed— a difficult proposition for densely populated countries. In addition, producing biomass for power generation is currently more expensive than using fossil fuels. Continued research is needed to develop high growth-rate biomass crops and low-cost harvesting techniques. Co-firing biomass and coal is a promising near-term option in existing power plants, and is already being used in the United States and other countries.

In the United States, most of the likely hydropower sites have already been developed and there have been calls by some in the environmental community to demolish some existing dams. Globally, many potential sites for hydropower exist. However, its development has been plagued with issues related to interference with fish migration and spawning, habitat destruction, and displacement of people. Geothermal power generation is another site-specific technology that has significant potential, but in a limited number of locations around the world. Cost-wise, wind power can be competitive, but issues, such as bird kill, visual impact, and noise, continue to be problematic in some areas. Wind power requires a windy site, a large land area, and usually a backup power source. Wind turbines effective under light wind conditions are a developmental goal. Finally, solar energy is an attractive option, but only suitable for locations with considerable sunshine. It is expensive because the conversion efficiency of solar cells is still relatively low. It will remain a low-power niche technology until lower-cost storage options are developed. However, photovoltaics are showing real promise in low-power demand, non-grid-connected applications, such as providing village power in developing countries. While renewable energy-based power technologies can meet the electricity needs of many parts of the world, they are generally incapable of producing enough power to satisfy the global demand for power.

The second technical option to reduce CO_2 emissions is efficiency improvement— both on the demand and supply sides. Improving the efficiency of energy use is a "no regrets" way to reduce GHG emissions. Of the highly developed countries, Japan, Italy, France, Germany, and England are noticeably more energy efficient than the United States. With less than 5% of the world population, the United States emits more than one-fourth of the world's total GHG emissions. Over our lifetimes, Americans use 500 times as much energy as residents of undeveloped countries. This results in part from different societal expectations in the United States compared with other countries and from real situational differences between the United States and other industrialized nations, e.g., the availability of low-cost energy, lower population density, and more extreme summer/winter temperature variations. There is no doubt that the United States needs to be more diligent about energy efficiency and conservation, and many demand-side opportunities exist, such as more efficient automobiles, buildings, and appliances.

On the supply side, major improvements in the efficiency of coal-fired power generation can be achieved with hybrid power cycles that operate at higher temperatures and pressures. Figure 4 illustrates three cycles that show this efficiency progression. Conventional coal-fired power plants raise superheated steam by burning pulverized coal in large, atmospheric-pressure power plants. Electricity is generated via the Rankine cycle by expanding high-pressure steam through a steam turbine to achieve efficiencies in the range of 34–42%. The practical efficiency limits of a simple Rankine cycle have been reached, but its efficiency can be improved by combining it with a Brayton gas-combustion cycle. In one example of a Brayton cycle, coal is gasified and then burned in a combustion turbine. Heat is recovered from the combustion turbine exhaust to raise steam in the Rankine cycle to achieve overall efficiencies in the range of 42–54%. Integrating a fuel cell with a combined cycle can further improve efficiency. In this arrangement, coal gas is first fed to the fuel cell, where most of it is electrochemically oxidized to produce electric power directly. The depleted fuel gas exiting the fuel cell is burned in a combustion turbine. A steam-turbine bottoming cycle completes the system to achieve overall efficiencies in the range of 58–70%.

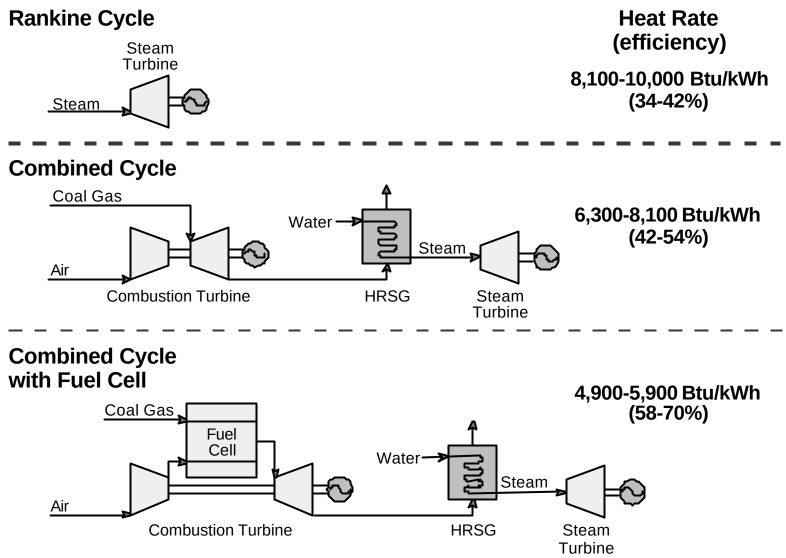

Figure 4. Efficiency Improvements in Advanced Coal-Fired Power Systems

Figure 5 shows CO_2 emissions from several power-generation technologies. The top four bars represent coal-fired technologies: conventional coal plants, Clean Coal Technology (CCT) demonstration plants, improved CCT plants, and Vision 21 plants. The bottom two bars represent natural gas-fired systems—currently available systems and advanced combined-cycle systems. Advanced coal technologies produce less CO_2 than conventional systems, but the figure also confirms that, owing to the lower carbon content of natural gas, natural gas-based power systems always produce less CO_2 than coal-based systems.

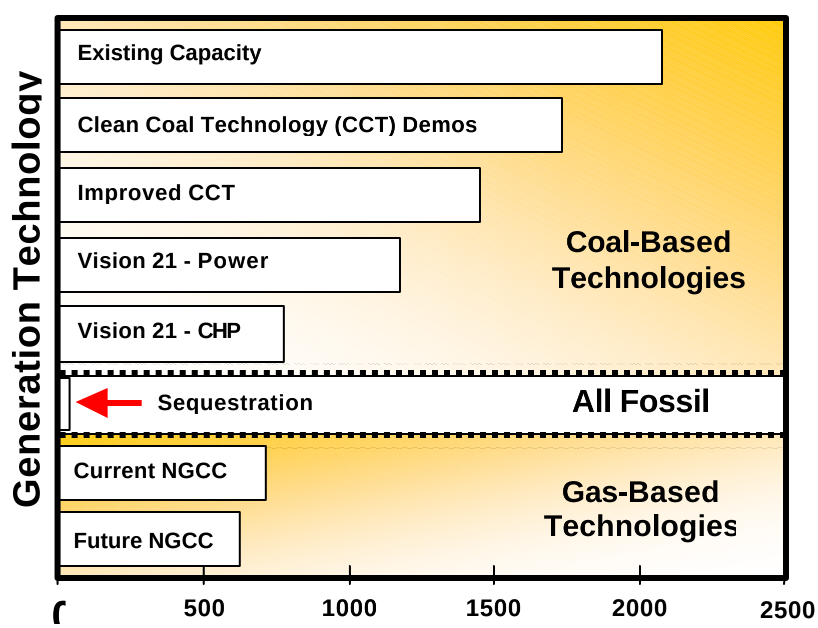

Figure 5. CO_2 Emission Rates of Various Fossil Fuel-Based Power Technologies

Vision 21 is part of the DOE's R&D program to develop the ultimate energy facility. Every usable Btu in coal or other carbon-based fuels will be used to produce electricity, process-heat, liquid fuels, chemicals, or a combination of these. The ultimate Vision 21 plant will have zero emissions— no net discharges of wastewater, solid waste, sulfur dioxide (SO_2), nitrogen oxides (NO_x), or CO_2. It will use sequestration to achieve zero CO_2 emissions, if required. An example of a Vision 21 plant is shown in Figure 6.

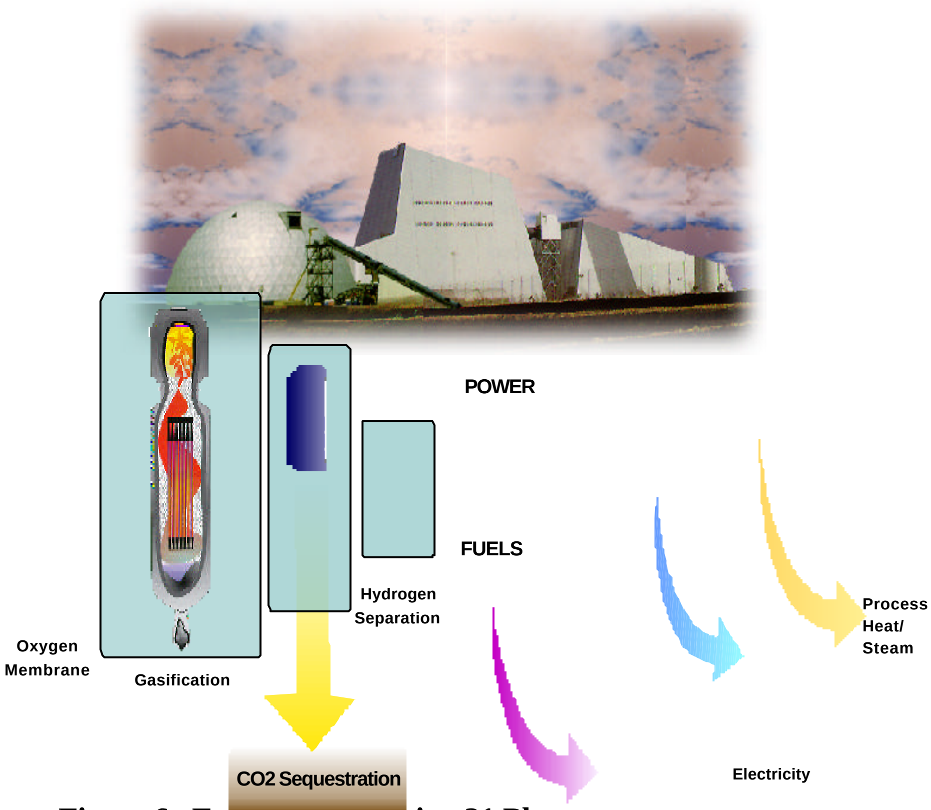

Figure 6. Example of a Vision 21 Plant

But improving efficiency and fuel-switching to natural gas will not be enough to solve the GHG emission issue over the long term— particularly if "science" determines that dramatic emission reductions are required. The goal of the 1992 Rio Framework Convention on Climate Change was to stabilize atmospheric CO_2 concentrations— not just reduce emission levels. Stabilizing CO_2 concentrations at whatever level society finds acceptable will require great reductions in GHG emissions. For example, to stabilize CO_2 concentrations in the atmosphere at 750 ppm— double their current level— the world's CO_2 emissions would need to be reduced to 30% of 1990 levels. To stabilize CO_2 concentrations at the current level of 370 ppm, the world's CO_2 emissions would need to be slashed to 10% of the 1990 level. Given the unlikelihood that the world's population will decide to reduce energy consumption more than 90%, the only realistic option to achieve these dramatic emission reductions is sequestration—the third technical option for CO_2 mitigation. The working definition of sequestration is the removal of greenhouse gases, usually CO_2, either directly from the exhaust gases of industrial or utility plants or from the atmosphere, and disposing of them either permanently or for geologically significant periods.

Figure 7 shows the three basic approaches to sequestration, the first of which is direct sequestration. Here, a concentrated CO_2 stream is captured inside a power plant and transported off site for long-term storage. The various storage options include injecting CO_2 into depleted oil and gas wells or saline aquifers, injecting CO_2 deep into the ocean, and injecting CO_2 into deep, unmineable coal seams. In the latter case, the coal seams retain the CO_2 and force out methane into a production well. This is convenient because coal-fired power plants are often located near deep, unmineable coal seams. However, several issues must be solved before any of these options can be considered viable for CO_2 storage, including the geologic integrity of storage sites, pipeline transportation costs, and potential accidental releases of large volumes of CO_2. Theoretically, oceans and geologic sinks have more than enough storage capacity to handle the CO_2 emissions that could be produced by burning all the known fossil fuel reserves.

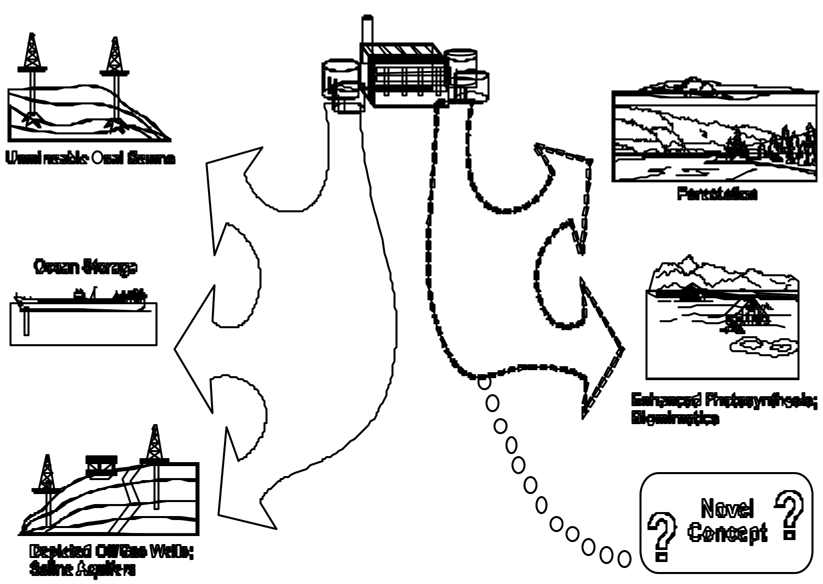

Figure 7. Three Basic Approaches to Sequestration

The second technical option is indirect sequestration. In this option, CO_2 is removed from the atmosphere by enhancing the ability of natural sinks, oceans or forests to absorb CO_2.

The third option to sequestration is the use of novel concepts. This includes revolutionary approaches such as the development of chemical or biological processes that mimic photosynthesis.

The DOE's Office of Fossil Energy began sequestration research in the early 1990s. DOE's sequestration program focuses on applied research and involves industry, universities, and national laboratories. It targets the longer term— to provide options for the period after 2015— and is pursuing many parallel approaches to sequestration. At the DOE's National Energy Technology Laboratory (NETL), lab-scale research is being conducted to better understand clathrate hydrate formation in oceans. NETL is also investigating geologic sequestration of CO_2 in coal seams to learn why CO_2 is more stable than methane in coal seams and to understand the influence of flue gas containing SO_2 and NO_x on microbial organisms in coal seams. In 1992, the DOE began collaborating with the International Energy Agency (IEA) on GHG emissions. Through the IEA Greenhouse Gas Program, Japan, Norway, and the United States are collaborating on a multimillion-dollar project to address the technical feasibility and environmental impact of pumping liquefied CO_2 deep (3,000 feet) into the ocean off the coast of Hawai'i. This effort is relevant to the 30% of US power plants that are within 150 miles of an ocean. The United States and Canada also have initiated a project to explore CO_2 sequestration in geological formations. The DOE's Office of Energy Research also has begun a carbon management research program, which addresses the material, chemical, energy, and biological science of carbon management—essentially, the fundamental science to support the Office of Fossil Energy's sequestration program. Development of cost-effective sequestration technologies compatible with the world's existing energy infrastructure could expand the technical options to mitigate GHG emissions from fossil-fuel-based power systems beyond efficiency improvement and fuel switching to biomass or natural gas. These technologies are feasible in some situations. For example, in 1996, the Norwegian oil company Statoil began storing CO_2 from a gas field in an aquifer beneath the North Sea. The amount of CO_2 sequestered annually is equivalent to that produced by a 140-MW_e coal-fired power plant. In addition, during the 1970s and 1980s, several commercial power plants separated CO_2 from flue gas using amine solutions, and subsequently used it for enhanced oil recovery. Today, the Alberta Research Council is injecting CO_2 into a deep coal seam to produce methane from a nearby production well. This small-scale test involves six other government participants, including the DOE's Office of Fossil Energy, and ten industrial organizations. Worldwide, forests are being replanted in several locations, which increases short-term carbon storage.

If the decision is made to limit CO_2 emissions from fossil-fuel-fired power systems to curtail global climate change, then all of these options most likely will be needed. Two-thirds of the world's total generating capacity of 3,075 GW_e in 1997 was fired with fossil fuels (IEA, 2000). Power plants fueled by coal, oil, and natural gas emitted a total of 8,942 million tons (mmt) of CO_2 in 1997— 70% of which was emitted by coal-fired power plants (IEA, 1999). Numerous opportunities exist on both the demand and supply sides for power sector efficiency improvements that will reduce CO_2 emissions. For example, NETL continues to work with the US Agency for International Development (USAID) to improve the performance— both efficiency and environmental— of coal-fired power plants in India. This work can serve as a global model for international cooperation in reducing both local and global impacts of coal-fired power generation. Other major coal-using developing countries, such as China and Indonesia, can look to this successful project for examples of cost-effective CO_2 emissions reduction from coal-fired power plants.

2) THE POWER SECTOR IN INDIA

India, with a total population approaching 1 billion, has a burgeoning middle class that is nearly as large as the total population of the United States—250 million. This middle class is driving India's future with regard to power generation and the environment. With an annual generation of only 430 kilowatt hours (kWh) per capita, India's power generation needs are very high, even in comparison to other fast developing countries, such as China and Mexico, which annually generate about 810 and 1,650 kWh/person, respectively (IEA, 2000). If such countries develop generation capabilities approaching that of the developed countries (United States: 12,450 kWh/person/yr, and western Europe: 5,400 kWh/person/yr), the resulting impact on the global environment will likely be severe.

India's current total installed generating capacity is about 93,250 MW_e of which about 65% is fired with coal. The country's thermal units (i.e., units fired with coal, oil, or gas) generated 355.8 billion kWh of electricity in 1997, or about 81% of the country's total electricity generation (i.e., utility + non-utility) (IEA, 2000). Non-utility power generators have about 12% of India's total generating capacity and produce about 9% of its electricity; in addition, all urban areas and about 85% of the villages in India are electrified (Tata Energy Research Institute, 1997). State Electricity Boards (SEBs) in India's 25 states generate a little more than 70% of the country's electricity and distribute most of the power. The central government supplies power to the SEBs through the National Thermal Power Corporation (NTPC) and the National Hydro-Electric Power Corporation. NTPC, the sixth-largest utility in the world, has an installed capacity of about 19,300 MW_e— about 20% of India's total capacity, and nearly 25% of India coal-fired power generation capacity. Most of NTPC's power plants are mine-mouth coal-fired units. NTPC generates more than 25% of India's total electricity with less than 20% of the country's generation capacity.

Despite significant government investment at both the national and state levels in all of the previous five-year plans, the gap has increased between peak demand and supply in India for all forms of energy, including electricity. Recently, India's electricity demand growth has been about 10–13% annually; however, supply has grown only 5–10% per annum during the same period (International Private Power Quarterly, 1999). Power supply in India is characterized by peaking and overall energy supply shortages. In 1995–96, India's peak generation capability fell short of peak demand by 18.3% (IPPQ, 1999). However, regional power shortages are much more variable— ranging from 0% to as high as 33% (IPPQ, 1999). Several years ago, the Central Electricity Authority forecasted that India would need a total generating capacity of about 386,000 MW_e by 2020—an addition of more than 300,000 MW_e in less than 25 years (Electricity International, 1995/1996). The capital cost of this expansion has been estimated at US$390 billion, but the transmission and distribution infrastructure required to deliver this power brings the total capital required to nearly US$800 billion (EI, 1995/1996). Recently, India's Power Secretary, V.K. Pandit, said that of the total incremental power requirement of 150,000 MW_e needed by 2002, only 28,000 MW_e of new generation capacity has been planned thus far (News Bridge, 2000). He also said that another 120,000 MW_e has been planned for the10 years after 2002. It has been estimated that as much 25,000 MW_e of the 57,000 MW_e of new capacity needed by 2003, and 56,800 MW_e of the 142,000 MW_e of new capacity needed by 2005, could be developed by the private sector (IPPQ, 1999). The NTPC plans to add another 10,000 MW_e of new capacity in the next five years, of which 6,000 MW_e will be coal based (NTPC, 1999).

Most new power plants in India will be fired by domestic coal, India's most abundant fossil fuel. Coal currently fuels some 70% of India's electricity; about 215 mmt of coal were used for electricity generation in 1997–98, and about 500 mmt are expected to be used annually by 2006–07. India's coal generally is of poor quality; its ash content often exceeds 40%. In other words, for every ton of coal burned, about 800 pounds of ash remains. Most of this ash ends up in landfills and ash lagoons, which can have an adverse impact on local ecosystems. Until recently, only 2–3% of the fly ash generated by India's coal-fired power plants was used productively; however, through efforts of the government and utilities, and with assistance from organizations like USAID and USDOE, that value has now risen to about 10%.

With considerable variability among the various generators, India's annual plant load factor (PLF) generally has been improving this decade, as shown in Figure 8 (Tata Energy Research Institute, 1997). The all-India average PLF has increased from 53.9% to 63%, which is several percentage points below the national average of developed countries such as the United States (65% in 1999). As shown in Figure 8, India's state-operated power plants have an average PLF about 10 percentage points below that of power plants in the central and private sectors. For example, in 1997–98 the NTPC, with only about 20% of India's generating capacity, had 7 stations among the 12 best-performing stations in the country in terms of PLF.

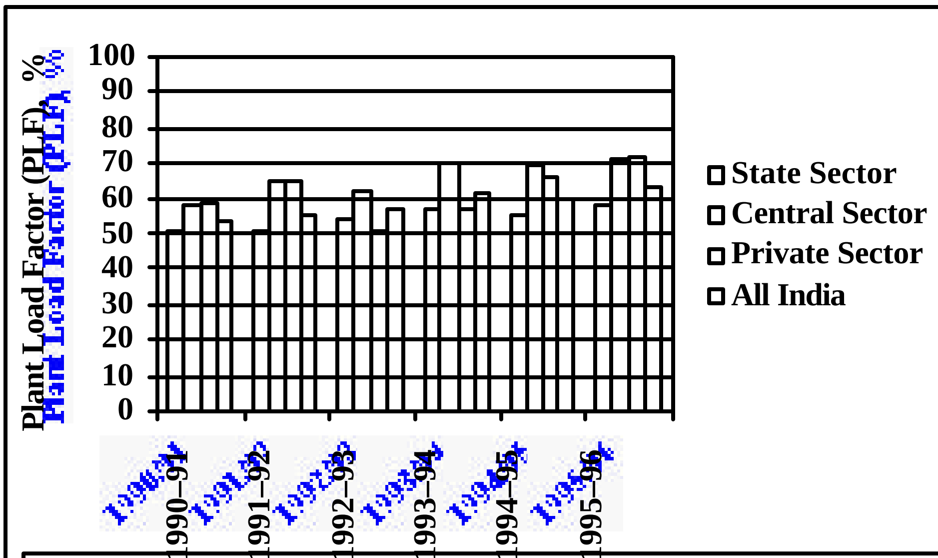

Figure 8. Plant Load Factors (PLF) for Indian Power Plants

To meet power demand in the regions of India that have not installed adequate new generating capacity, some very inefficient power plants continue to operate. For 1994–95, Figure 9 shows the share of total electricity generation from all Indian thermal power plants by level of overall plant efficiency (Tata Energy Research Institute, 1997). While the average for all Indian units is in the 25–30% range, some operating units have an overall efficiency of less than 15% (0.31% of total generation). By comparison, the average heat rate for all US coal-fired power plants in 1997 was 10,309 Btu/kWh (i.e., 33%).

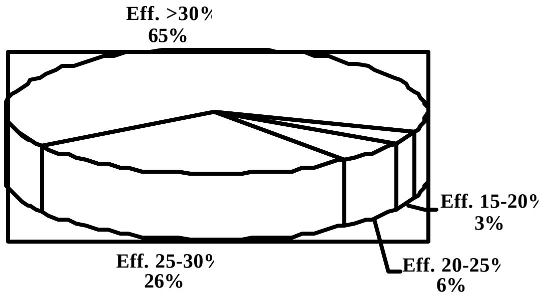

Figure 9. Shares of Total Indian Electricity Generation by Level of Plant Efficiency

The reasons for such low efficiency are threefold: (1) some of India's existing thermal power plants are very old (30–40 years) and were installed when design efficiencies were very low by today's standards; (2) some plants employ inherently lower-efficiency thermal power generating technologies, such as diesel engines; (3) owing to their financial situation, many of India's utilities lack the funds to properly maintain their generating units, thus their performance has degraded; and, (4) many of India's utilities lack either the technical or managerial know-how, or the equipment, necessary to properly maintain their units. With technical assistance from the developed countries, units in the last category can readily be brought up to their design basis. hen returned to peak performance, such units will have higher efficiencies, and thus lower operating costs and lower levels of CO_2 emissions.

3) USAID-INDIA GEP PROJECT

Given the country's demand for electricity, and the lack of fuel options other than coal, India needs to ensure the efficient operation of its existing coal-fired power plants and to begin deploying a new generation of more efficient, environment-friendly, coal-fired power plants. To help meet this need, USAID— through a series of agreements with NETL and its predecessor organizations— has conducted a series of multiyear technical assistance projects with Indian companies and organizations since the early 1980s. The general aim of these projects is to improve the efficiency and reduce the environmental impact of using coal in India for power generation. These projects have also provided stepping stones for US businesses to enter Indian coal and power-generation markets. To assist with the direction and pace of India's power sector development, USAID-India initiated the Greenhouse Gas Pollution Prevention (GEP) Project in 1995. This seven-year, US$30-million project, of which US$19 million is part of the United States' commitment to the pilot phase of the Global Environmental Facility (GEF), is jointly funded by the United States and India. The GEF's mission is to help developing countries invest in environmental protection initiatives that yield global benefits in terms of reduced or avoided GHG emissions. The GEF was established in cooperation with the United Nations Development Program (UNDP) and the World Bank following the 1991 environmental summit held in Rio de Janeiro, Brazil. Through a US$6.6-million Participating Agency Service Agreement (PASA), NETL is providing technical assistance for project implementation. To effectively support implementation of the GEP Project, NETL stationed a senior resident advisor in India for two consecutive two-year assignments starting in 1995. Most of the power plant efficiency improvement activities in the ongoing project will be completed in early 2000. USAID-India is planning to follow the first phase of the GEP Project with a Global Climate Change Supplement that will build on the successes of the current phase.

The objective of the GEP Project is to reduce GHG emissions from existing Indian power generation facilities; the Project has two components: Efficient Coal Conversion (ECC) and Advanced Biomass Cogeneration (ABC). The ECC Component is demonstrating state-of-the-art approaches to improve the thermal and environmental performance of existing coal-fired power stations through the Centre for Power Efficiency and Environmental Protection (CenPEEP), which was established by NTPC at their R&D Centre at Noida. CenPEEP was inaugurated in July 1994 by Hazel O'Leary, then US Secretary of Energy.

CenPEEP will assist coal-fired power stations in India by serving as a national resource center for the acquisition, demonstration, and dissemination of leading-edge technologies and practices in the areas of improved availability, reliability, efficiency, and the environment (including GHG reduction). Eventually, CenPEEP will support all Indian utilities on a cost-recovery basis by providing services in power plant life extension, preventive maintenance, efficiency improvement, environmental monitoring and compliance, and ash management/utilization. The ABC Component of the GEP Project concentrates on the year-round (i.e., minimum of 270 days) use of biomass fuels for efficient cogeneration in the Indian sugar industry. The project will work with Indian sugar mills to promote cogeneration with year-round export of power to the grid by supplementing their traditional fuel, bagasse, with other biomass fuels, such as cane trash and rice hulls.

Working with NTPC and a number of India's SEBs, the ECC component addresses problems in existing coal-fired power plants through the following tasks:

- Power Plant Efficiency Improvement;
- Plant Condition Monitoring and Assessment;
- Environmental Monitoring and Control;
- Advanced Power Generation;
- Fly Ash Utilization; and,
- Coal Quality.

On the Power Plant Efficiency Improvement Task, technical assistance has been provided by NETL (including its site-support contractor, Science Applications International Corporation/SAIC), EPRI (Electric Power Research Institute), and TVA (Tennessee Valley Authority). The Southern Research Institute, the University of Southern Illinois, GAI Consultants, and a number of other US firms have provided additional technical assistance on other project tasks.

Power Plant Efficiency Improvement Task

Led by NETL, more than a dozen technical teams have traveled from the United States to NTPC/SEB stations in India to provide technical assistance totaling more than 400 man-days. Indian power-plant engineers have received more than 3500 man-days of training in the latest techniques. About a dozen workshops and training courses have been organized, along with several large international meetings that have been well attended by many US firms. Several issues of a CenPEEP newsletter have been sent to all utilities and thermal power stations in India.

Among the various training and demonstration activities under the GEP Power Plant Efficiency Improvement Task are:

- acquisition and training in use of US industry-standard software for power plant performance optimization;
- acquisition and training in use of US industry-standard instrumentation for:
- optimization of fuel-air ratio using dirty pitot tubes;
- measurement of unburnt carbon in fly ash using isokinetic and high-volume sampling probes;
- measurement of boiler temperature using water-cooled High Velocity Thermocouple (HVT) probes to optimize combustion;
- measurement of condenser air-in-leakage using a helium leak detector; and,
- measurement of condenser back pressure.
- acquisition and training in use of on-line software for plant heat-rate (i.e., efficiency) measurements;
- System-wide optimization of high-pressure-feed and low-pressure-feed water heaters, condenser, boiler, and boiler feed pump using a portable data-acquisition system and on-line software.
- acquisition and training in use of a US condenser-cleaning system;

In addition, training has been provided to Indian utility engineers in the conduct of numerous standard power-plant-testing procedures related to:

- air preheater performance;
- boiler efficiency;
- mill performance optimization (coal and air flow balance);
- condenser performance (air inleakage and back pressure);
- boiler performance optimization;
- turbine enthalpy drop;
- boiler feed-pump performance;
- high-pressure-feed water heater performance;
- low-pressure-feed water heater performance; and ,
- turbine cycle heat rate.

Condenser performance has been taken up as a high priority in the Power Plant Efficiency Improvement Task of the GEP Project because it has a dominating influence on power plant efficiency and availability. For example, EPRI has estimated that the loss of unit availability directly attributable to condenser problems at large ($\geq$600 MW_e) US fossil-fuel-fired power plants is 3.8% on average. Condenser-related problems cost the US electric power industry at least US$600 million annually for replacement power alone. From the standpoint of efficiency, a higher than expected condenser back-pressure results in a lower Rankine cycle efficiency and higher plant heat rate.

Under the Power Plant Efficiency Improvement Task, the initial demonstration activities at NTPC's Dadri power plant (4 x 210 MW_e) improved overall plant efficiency by more than1.5%. Subsequently, coal use has been reduced by more than 81,000 tons/yr, reducing NTPC's fuel costs by more than US$2.4 million/yr. CO_2 emissions at Dadri also have been reduced by more than 100,000 tons/yr. Figure 10 shows the heat rate of the four individual units and overall station before and after implementation of plant improvement supported by the GEP Project.

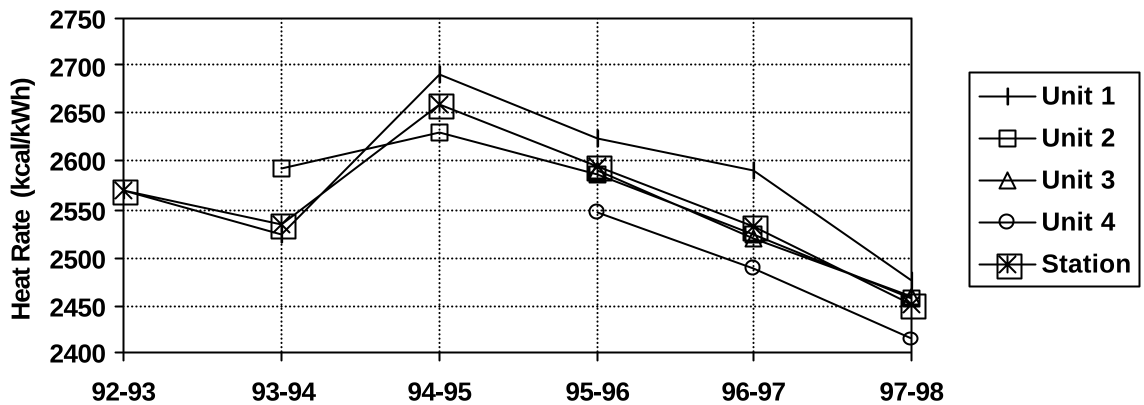

Figure 10. Heat Rate Improvement at NTPC's Dadri Station

Replication of the work at Dadri has been completed or is under way at 7 other plants totaling 9,100 MW_e. Following are the NTPC and SEB coal-fired power plants where efficiency improvements have been performed, along with the total generating capacity of each station.

- NTPC's Dadri Station (840 MW_e)
- Madhya Pradesh SEB's Rihand STPS (1,000 MW_e)
- Uttar Pradesh SEB's Singrauli Station (2,000 MW_e)
- Gujarat SEB's Wanakbori Station (1,260 MW_e)
- Bihar SEB's Kahalgaon Station (840 MW_e)
- Madhya Pradesh SEB's Vindyachal Station (1,260 MW_e)
- Delhi Electric Supply's Badarpur Station (705 MW_e)
- Andhra Pradesh SEB's Ramagundam Station (2,100 MW_e)

Every plant was found to have the potential to improve its efficiency by 1to 2%. As an example of GEP Project achievements at a SEB power plant, Figure 11 shows the heat rate and PLF improvements for Gujarat SEB's Wanakbori Station.

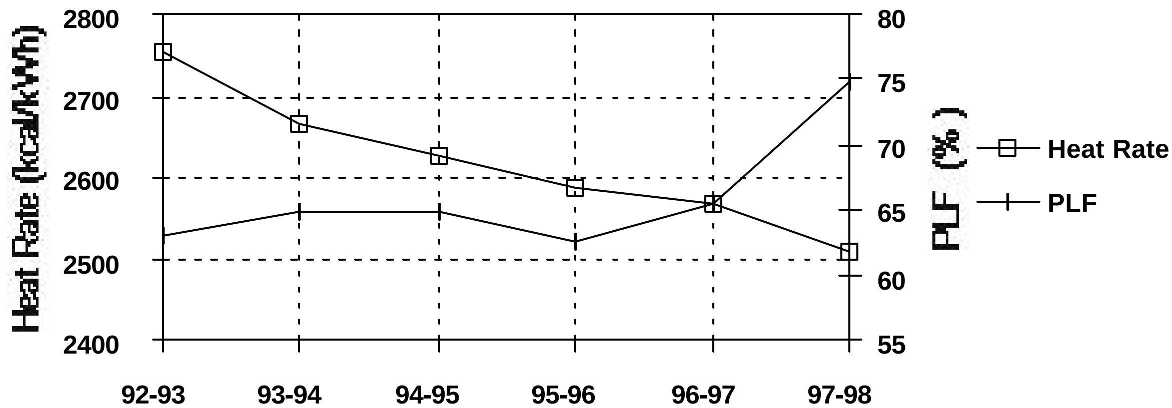

Figure 11. Heat Rate and PLF Improvement at GEB SEB's Wanakbori Station

In many cases, the fuel cost-savings to these power plants significantly exceeded the costs associated with the efficiency improvement. Based on the accomplishments at Dadri, NPTC has issued a directive to all its power stations to target a heat-rate reduction of 1%, or at least 25 kcal/kWh. For 1998, NTPC power stations reported reductions in coal use worth US$25 million. To date, the CO_2 reductions from these plants total more than 2 mmt. To sustain this high-performance level, NTPC stations have been directed to establish performance optimization groups for daily monitoring of heat rate and to ensure that all units attain the "best achievable" heat rate.
These activities can be replicated at more than 130 similar 200–210-MW_e units in India. Based on results to date, CO_2 emissions from India's power sector are expected to be reduced by more than 10 mmt/yr by 2010 while fuel costs are lowered by more than US$150 million/yr. With minor modifications, the efficiency improvement activities could be adopted by Indian power plants with a capacity near 60,000 MW_e. Other efficiency improvements identified at Dadri, but not implemented yet owing to their higher capital costs, point to a total CO_2 reduction potential of more than 25 mmt/yr for all Indian plants.

Advanced Power Generation Task

Under the Advanced Power Generation Task, more efficient, advanced power-generation technologies are being promoted, including supercritical pulverized-coal boiler and integrated gasification combined cycle (IGCC) technologies. India has yet to erect a supercritical pulverized-coal boiler, which raises the efficiency of power generation from about 36% to about 42%, but NTPC is considering its first unit. India also has been investigating IGCC for many years with several preliminary feasibility studies and pilot-scale testing programs completed. Information on the three large IGCC demonstration projects in the DOE's Clean Coal Technology Program has been shared with India, and a number of Indian delegations have visited the project sites. An existing Life-Cycle Cost

Model is being extensively updated and expanded to allow Indian engineers to develop comparative cost estimates for various advanced-coal power-generation technologies.

Other GEP Project Tasks

Most Indian power plants use electrostatic precipitators (ESPs) to remove the fly ash from power-plant flue gases. Owing to the high ash content of most Indian coals, particulate emissions from Indian power plants are very high. This problem is compounded by the fact that many power plants burn coals with much higher ash contents (>40%) than the existing ESPs were designed to handle. Under the Environmental Monitoring and Control Task, US testing and operation procedures for ESPs have been demonstrated at several plants. For example, water fogging has been shown to reduce particulate emissions from the overburdened ESPs by 30–40% at a very low cost.

India currently produces more than 60–70 mmt of coal combustion byproducts from power generation, of which somewhat less than 10% are utilized (compared to 25–30% in the US). Under the Fly-Ash Utilization Task, a number of options to increase beneficial fly-ash utilization in India are being promoted, including use in cement, brick, and aggregate, and in low-value, high-volume applications such as mine and structural fills. For example, an ash haul-back demonstration project supported through the GEP Project is returning ash to the mine site.

Future GEP Project Activities and Conclusion

Based on the success of efforts to date, USAID has approved additional funding for Phase II of the GEP Project. NETL will continue to provide technical assistance to Indian project participants over the next 5 years. The second phase of the GEP Project envisions institutional strengthening of CenPEEP, and creation of regional centers similar to CenPEEP, to promote efficiency improvement in coal-fired power plants throughout the country. . The next phase will also assist in building local capacity to sustain GHG reductions in existing coal-fired power stations and to slow the rate of new power-plant additions through more efficient generation and better utilization of existing generating assets. The ongoing work can serve as a global model for international cooperation in reducing both the local and global impacts of coal-fired power generation. Other major coal-dependent developing countries, such as China and Indonesia, can look to this highly successful project for examples of cost-effective CO_2 emission reduction from coal-fired power plants via efficiency improvement.

4) REFERENCES

Energy Information Administration, US Department of Energy. January 2000. *International Energy Annual 1998*, DOE/EIA-0219(98).

International Energy Agency. 1999. *CO_2 Emissions for Fuel Combustion 1971-1997*.

Tata Energy Research Institute. 1997. *TERI Energy Data Directory & Yearbook 1997/1998*.

The McGraw-Hill Companies. Fourth quarter 1999. *International Private Power Quarterly*.

Electricity International. December 1995/January 1996. *Government Planner Hard at Work*.

Bridge News Media via www.individual.com. February 23, 2000. “India aide says pvt sector can bridge power demand-supply gap.”

National Thermal Power Corporation, private communication. 1999.